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THE EFFECT OF SUBSTRATE POTASSIUM, SUBSTRATE TEMPERATURE  
AND LIGHT INTENSITY ON PLANT GROWTH  
AND THE UPTAKE OF MAJOR CATIONS BY TOMATO PLANTS

by



CHIN BAE CHU

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FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled

"The Effect of Substrate Potassium, Substrate Temperature  
and Light Intensity on Plant Growth  
and the Uptake of Major Cations by Tomato Plants"

submitted by Chin Bae Chu, in partial fulfilment of the requirements for the degree of Master of Science.





## Abstract

The effect of substrate temperature and light intensity on plant growth and the uptake of major cations was studied in tomato plants, *Lycopersicon esculentum* Mill. cv. Michigan-Ohio Hybrid, grown under four temperature and two potassium substrate levels in the greenhouse and two potassium and three temperature substrate levels and 2 levels of light intensity in a growth chamber.

The substrate temperature and light intensity had an influence on potassium-magnesium antagonism and the subsequent uptake of major cations.

High substrate temperatures (23.9 and 29.4 C) coupled with high substrate potassium (12 meq  $K^+$ /liter) favored early maturity of the flowers and this effect was enhanced further with higher light intensity (1500 f.c.).

At the lowest substrate temperature (12.8 C) the plants receiving higher light intensity (1500 f.c.) tended to be taller than those receiving the low light intensity (750 f.c.) under both levels of substrate potassium (4 meq  $K^+$ /liter and 12 meq  $K^+$ /liter). As substrate temperature (23.9 and 29.4 C) was increased the effect of potassium on plant height decreased and the effect of light intensity increased.

High substrate potassium, higher light intensity and high substrate temperature (29.4 C) appeared to improve stem growth. However, it appeared that high light intensity and high substrate potassium would tend to aggravate the problem of potassium induced magnesium deficiency. Potassium-magnesium antagonism appeared to be enhanced by higher light intensity (1500 f.c.) in combination with low substrate temperature



(12.8 C). Statistical analysis did not support the possibility that substrate temperature alone has a direct effect on potassium-induced magnesium deficiency.

Although changes in pH did occur in the nutrient solutions under different substrate temperature regimes it did not affect uptake of any of the cations involved in these studies.





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## Introduction

Production of greenhouse vegetable crops has increased in the past few years in Alberta. Recent surveys indicated the greenhouse vegetable industry has increased at about five to six per cent per year in recent years. The vegetable industry should continue to grow as the market appears to be receptive for the high quality tomatoes and cucumbers produced.

Greenhouse tomatoes must have a proper balance of mineral nutrients continuously to produce a full crop of high quality fruit. The fertilizer containing the nutrients must be applied at the right times and in the correct amounts.

The uptake of nutrients is an essential part of the growth process, and if the rate of uptake does not keep pace with growth, the concentration of the nutrient in the plant tissue must decrease. Where diffusion is the main transport mechanism, there will be a depletion of nutrient around the roots.

In greenhouses magnesium deficiency has been observed with considerable frequency on crops such as tomatoes, cucumbers, and chrysanthemums. Tomato plants showing characteristic symptoms of magnesium deficiency have been observed in greenhouses in the Medicine Hat area of Alberta.

In the field-grown crops magnesium deficiency occurs on soils low in exchangeable magnesium, but in the greenhouse it is more often associated with excessive applications of other nutrient elements, particularly potassium.



Potassium-induced magnesium deficiency and its effect on growth, yield and mineral composition of susceptible crops has been investigated by others. The possible influence of soil-root temperature and light intensity on nutrient uptake was also investigated. That "soil" temperature would have a possible role in aggravating the problems was suggested by the fact that magnesium deficiency occurs more commonly on warm crops than on cool crops. Results of earlier experiments indicated that the substrate temperature, rate of potassium fertilization, and light intensity all had a possible influence on the incidence of magnesium deficiency (Kabu and Toop 1970a, 1970b). A high rate of potassium fertilization and high "soil" temperatures could act together in aggravating the symptoms of magnesium deficiency. Under high light intensity there was a trend towards less magnesium uptake than under low light conditions. Several references have been made to magnesium deficiency induced by potassium fertilization and some of the factors that influence it (Greenham 1965; Hohlt and Maynard 1966; Kabu and Toop 1970a, 1970b; Ward 1967c; Ward and Miller 1969; Welte 1963; Froshey 1963; Holmes 1962). However, little research has been conducted on the influence of soil temperature in combination with light intensity on nutrient uptake by plants.

The objective of this study was to determine potassium-induced magnesium deficiency at various "soil" temperatures in greenhouse tomatoes and the effect of various "soil" temperatures in combination with light intensity on the growth and their interaction relationship in the growth chamber.





## Literature Review

### Magnesium deficiency symptoms

Magnesium deficiency has been observed by many others. The importance of magnesium as a field fertilizer was first recognized for tobacco (McMurtry 1947). The characteristic symptoms of magnesium deficiency were called "sand drown" before the cause of the condition was known. The deficiency is characterized by a loss of green color in the lower leaves of the plant, beginning at the leaf tip and progressing inward along the margins and between the veins. The visual symptoms of magnesium deficiency have been described and illustrated by Embleton (1966), Jacob (1968), Sprague (1963) and many others. As a general rule the most common symptom of magnesium deficiency in tomato crops is intervenal and marginal chlorosis. The yellowing of the foliage characteristic of this deficiency first appears among the middle leaves of the plant, is usually most severe in mid-season, and may subsequently become less prominent as the removal of leaves is continued upward from the base.

### Occurrence of magnesium deficiency

Ion interactions have been defined by Emmert (1961b) as the enhancing or depressing influence of one ion in a tissue on the accumulation of other ions of dissimilar species in that tissue. The nutrient ions do not change in concentration in a tissue in a singular and isolated manner. A change in content of one ion is invariably accompanied by secondary changes in tissue content of other dissimilar ions, even though availability to the plant of the ions interacted



upon remains unchanged.

The application of any one fertilizer to the soil can affect the composition of plants with regard to elements other than those applied. The supply of magnesium to the crop can be affected by the application of other nutrients. (Winsor and Long 1963).

Jacob (1958) defines "ion antagonism" as the frequently observed phenomenon whereby the uptake of an ion by the plant is inhibited by the increased supply of other ions whether as a result of soil processes or the influence of the plant itself. This ion antagonism can also be expressed as the interaction of ions involving the depressing influence of one ion on the other ion. The deficiency of a nutrient in a plant resulting from ion antagonism is usually referred to as "induced deficiency". The antagonistic effect of potassium on magnesium is greatest when substrate magnesium is relatively low.

If the plant-soil system is regarded as a Donnan system consisting of two colloidal phases, the relative distribution of cations of different valence between the two phases will depend upon the exchange capacity of both plant roots and clay mineral particles. Accordingly, other things being equal, the same plant is expected to take up larger proportions of the monovalent cations and smaller proportions of the divalent cations, the higher the exchange capacity of the clay mineral (Bear 1964). Welte and Werner (1963) differentiate between physico-chemical cation interactions and specifically physiological antagonisms. The exchange-adsorption of magnesium and other cations at the sorption complex of the soil as well as at the sorption sites in the 'free space' of the plant root is governed by the physico-



chemical Donnan laws. Thus in magnesium deficient soil with high sorption capacity in which the Mg-ions are intensely bound, an application of potassium can improve the magnesium supply of the plant by releasing part of the bound Mg-ions from the sorption complex. However, in coarse soils low in sorption capacity this displacing action of potassium can reduce Mg-supply to the plant by promoting the leaching of this element.

The physiological antagonism is based on the ion competition for the sorption sites of the organic structures functioning as 'carrier' molecules in the process of active cation uptake. The competition between cations during entry into plant roots growing in soil are based on the equilibrium of the cation activity ratio. This ratio reflects the outcome of the competition (Arnold 1968).

Welte and Werner (1963) studied the effect of increasing amounts of K on the Mg-content as well as of increasing amounts of Mg on the content of K in maize. They found that high K-concentrations in the substrate decreased the Mg-content of the plant, and lower K-contents were caused by an increased Mg-application. From the physiological point of view this means that the interaction between these cations is a true antagonism.

Drew et al (1969) stated that potassium uptake from soil by roots of comparable absorbing power can be accounted for solely by the diffusion supply process and the geometry of the absorbing root surface. The relation between uptake and characteristics of the plant and soil is interpreted on the basis of a diffusion supply model. Uptake is accounted for in terms of the geometry of the absorbing





root surface, the physiologically controlled absorbing power of the roots, and the diffusion through the soil. According to Jacob (1958) the differences in speed of diffusion can cause certain ions with higher mobilities to enter plant cells preferentially and thereby disturb the equilibrium. The ions entering more quickly can make more difficult the entrance of more slowly moving ions. An excessive supply of certain ions can impede the uptake of such ions as are present in only small amounts in the nutrient medium.

The diffusion is generally an important process for potassium. Ability to supply depends on concentration in the soil and mobility, expressed as the diffusion coefficient.

The diffusion coefficient for  $K^+$  varies with the amount that is diffusible and depends on the slope of the relation between the exchangeable  $K^+$  and the soil solution  $K^+$ . The supply of  $K^+$  in soils available to plant roots will thus be affected by the changing soil solution concentration and the concurrent depletion of the exchangeable  $K^+$  near the root surface.

In the plant the magnesium ion is exposed to a whole series of antagonistic ions such as Ca, H,  $NH_4$ , Mn and K (the most important of all). Cain (1953) observed that a given ion has little if any direct effect on the total absorption of another by apple trees although the percentage composition of one ion may be decreased by the application of another if its rate of absorption does not keep pace with the rate of growth stimulated by the added ion. If the addition of one ion caused an increase in dry weight of the plant, there was generally more total absorption of all nutrient ions although some



plant parts may show a net loss of some ions. If there was no growth response, only the ion applied was absorbed in greater quantity.

Sometimes an apparent ion-interaction can result merely from the dynamic influence of an added element like nitrogen on plant growth; the increased tissue volume results in a dilution of other elements in the tissue.

#### Inherent magnesium deficiency

A deficiency of magnesium is less of a problem on finer-textured soils and soils of the arid regions. However, a deficiency of magnesium is generally manifested on coarse-textured soils of the humid regions (Tisdale 1970, Embleton 1966). These soils normally contain only small amounts of exchangeable magnesium, a condition that is aggravated by the addition of large quantities of fertilizer salts which contain little or none of this element. The magnesium in these soils is released by ion exchange when these fertilizers are added. Large quantities of chlorides and sulfates enhance its removal in percolating waters. On humid-region, coarse-textured soils, the deficiency of magnesium in the plants is usually less pronounced in the years of relatively low rainfall. On the other hand, the soils normally contain inadequate amounts of exchangeable magnesium which are easily leached under heavy rainfall (Salmon 1963). Besides the permeability of soil, the soil reaction is an important factor determining the extent of magnesium leaching. Because magnesium goes into solution to a greater degree in acid soils than in neutral or alkaline soils it is more strongly leached out under acid conditions than under



alkali conditions (Embleton 1966). Nevertheless magnesium deficiency has been reported on alkali soils by Heymann-Horschberg in Israel (Embleton 1966). Woodbridge (1955) reported deficiencies in apple orchards of British Columbia on soils ranging in pH from 4.9 to 8.2.

#### Potassium-induced magnesium deficiency

Ward and Miller (1969) reported that magnesium deficiency is particularly noticeable in greenhouse vegetables such as tomatoes and cucumbers. In the greenhouse it is more often associated with excessive application of other nutrient elements, particularly potassium. The visible symptoms of severe deficiency in leaf tissue are quite characteristic and probably the most easily recognized of any of the nutrient deficiency symptoms. Salmon (1963) reports that glass house and horticultural crops have suffered more often than farm crops from magnesium deficiencies, which have usually been associated with large potassium dressings. Magnesium deficiencies in crops are caused not only by inadequate exchangeable solution magnesium, but also by ion antagonism in acid soils and soils rich in potassium.

Boynton and Burrell (1944) stated that magnesium deficiency was induced by the action of potassium in mutual ion replacement or ion competition, on the absorption mechanism of the roots or within apple trees rather than in the soil. Magnesium-deficiency leaf blotch was induced in McIntosh apple trees on acid soil low in exchangeable bases as a result of fertilization for 3 or more years with potassium fertilizer. Decrease in leaf magnesium and increase in leaf potassium accompanied the appearance of the symptoms. Walsh





et al. (1946) indicate that the absorption of magnesium by plants may be depressed under the influence of an excess of other nutrients, notably potassium and calcium, in the soil. The symptoms of magnesium deficiency in plants have been noted as a result of heavy potash fertilizing, despite an apparently adequate concentration of magnesium in an easily available form in the soil. The references to the aggravation of magnesium deficiency by potash fertilizing occupy quite a sizeable space in the literature.

The accentuating effect of potassium on magnesium deficiency was first pointed out by investigators such as Kidson, Southwick and Wallace in the late '30's of the present century. Drosdaff and Kenworthy (1944) suggested that the severity of the magnesium deficiency in the Brooker, Florida, orchards was accentuated by previous applications of approximately 5 tons per acre of tunghulls, which may contain up to 3.5 per cent  $K_2O$ . They further found potassium was less harmful when applied to trees that received epsom salts. Prince et al. (1947) found that the most important single factor influencing the magnesium uptake of plants is the quantity of K that is available for their use. If an abundance of K is at the plants' disposal, its content of Mg will be relatively low. They concluded that it is advisable to use additional Mg as larger amounts of K are applied to the soil. Walsh and O'Donohoe (1945) recommended that the potassium/magnesium ratio of both the soil and plant merits attention when attempting to account for the development of magnesium deficiency. The wider the ratio in each case the greater is the tendency towards the development of magnesium deficiency. The ratio of potassium to magnesium has a direct



relationship to the relative amount of these elements available for absorption. Van Der Boon et al. (1966) observed that magnesium deficiency in the foliage of apple trees (Cox's Orange Pippin M IV) was increased by dressing with potassium and diminished by application of magnesium. Magnesium deficiency was most closely related to the K/Mg-ratio in soil, foliage and fruit. They claim that no magnesium deficiency will occur in apples when the  $K_2O/MgO$ -ratio is less than 0.6 in the soil and less than 6 in the foliage. Dressing had the least effect on the nutrient content of the fruit. Dressing with potassium increased both the potassium and magnesium content in the fruit.

Bingham et al. (as reviewed by Chapman 1961) found that potassium-induced magnesium deficiency occurred on orchard soils of California where the ratio of exchangeable potassium to magnesium exceeded 0.5. Where the ratio was below 0.5 no magnesium deficiency occurred. Welte and Werner (1963) reported that at normal nutrient conditions the ratio K/Mg in the plant generally varies between 7 and 10. Potassium induced magnesium deficiency symptoms can occur in arable crops if the K/Mg ratio exceeds about 15-20, provided that the absolute Mg-level of the plant is relatively low. This critical ratio varies with different plant species. As the K-ion is more favourably absorbed by the plant than magnesium ion and as the magnesium uptake is more or less inhibited by other cations, the ratio of available K to Mg in the soil must be less than the K/Mg ratio in the plant. McColloch et al. (1957) report that an exchangeable K/Mg value greater than 0.4 to 0.5 is suggestive of Mg deficiency in citrus. The ratio will indicate when Mg should be applied with K in order to reduce the pos-



sibility of potassium-induced Mg deficiency. They also found that the exchangeable K/Mg ratio of the soil could be used to describe the Mg content of the foliage: 83% of the variance in leaf Mg was related to the variance of the exchangeable K/Mg ratio of the 18 to 30 inch soil depth. However, only 28% of the variance in leaf Mg could be related to the variance in per cent saturation of K in the 18 to 30 inch soil depth.

#### Potassium uptake by the plant roots

The supply of potassium in soils available to plant roots will be affected by the changing soil solution concentration and the concurrent depletion of the exchangeable K near the root surface (Drew et al. 1969). The initial solution concentration and the root absorbing power are the factors controlling uptake. Labile K concentrations may be reduced depending on the diffusion characteristics of the soil and nutrient demand by the root. The presence of root hairs affects uptake of potassium (Drew et al. 1969, Olsen and Kemper 1968). Arnold (1968) reports that ion uptake by roots is concentration, or more strictly, activity dependent. In addition to external concentration, the influence of other ions and the rate at which metabolic processes utilize ions are important. In considering how exchangeable, or labile, cations associate themselves with negatively charged soil colloids, it is to be expected that coulombic forces play an all important role in counteracting the kinetic energy of the cations. In addition, there is invariably at least some specific interaction between colloid surface and adsorbed cations, which can be held very close to the





surface with special affinity. Elgabaly (1949) states that the difference in ion uptake could be attributed mainly to the influence of the medium. Clay minerals with high exchange capacity and high activity, release their monovalent ions to the plants more readily and divalent ions less readily than do clay minerals with lower exchange capacity.

#### Factors affecting magnesium deficiency

##### pH

The effect of the pH of the nutrient medium on the uptake of inorganic nutrients in general and of magnesium in particular has been studied by a number of authors. The development as well as the functioning of the roots may be affected by pH for a considerable length of time in nutrient media.

Ferrari and Sluijsman (1955) who studied the magnesium nutrition of oats growing under field-experiment conditions, found that when equal contents of available magnesium were present in the soil, more pronounced symptoms of magnesium deficiency occurred at a low than at a high pH.

In the investigations of Arnon (1939), (pH range from 5 to 6.7), Wadleigh and Shine (1939), (pH range from 3 to 9), and Olson (1953), (pH range from 4 to 9), the effect of the pH of the nutrient medium on the uptake of inorganic nutrient from culture solutions was found not to be very pronounced. Mulder (1956) concluded that the effect of low soil pH on magnesium uptake is not the main reason for the occurrence of magnesium deficiency in plants growing in acid soils.





Low soil pH may contribute, however, to the poor development of magnesium deficient plants on soils already poor in available magnesium. A reduced acidity (higher pH) of the soil enables the plant to take up more magnesium because of a better developed root system and/or a better functioning of the roots (less competition of H-ions).

The magnesium content of plants is affected both by the soil pH and the available potassium. Welte and Werner report that raising the pH by liming without adding magnesium was more effective in improving magnesium uptake and growth than an addition of magnesium without correcting pH. The K/Mg antagonism is the more pronounced the lower is the pH. The antagonistic effect of the  $H^+$  ion on Mg absorption by plants is stronger than that of  $K^+$  ion. However, Adams and Henderson (1962) found that magnesium contents of plants at deficient K levels were greater than at adequate K levels for the same soil, regardless of soil pH. The effects of K and soil pH on Mg content of plants appeared to be largely independent of each other. Mg content was affected by soil pH in some instances but the effect was independent of potassium level.

### Concentrations

Adams and Henderson (1962) found that the effect of K on magnesium content was generally greater on Mg-sufficient soils than on Mg-deficient soils. However, plants had a higher Mg content at deficient-K than at adequate-K. Minimum Mg concentrations in the plants appeared to be a suitable indicator of Mg-deficient soils where adequate K and lime were added. According to Welte and Werner



(1963) magnesium deficiency will occur where soil-Mg is at deficiency-levels and that only under these circumstances may generous potash-dressings have an aggravating effect. On those soils the object should be to accumulate soil-Mg by fertilizing to a sufficient level. Ward and Miller (1969) were not successful in producing the symptoms of magnesium deficiency in greenhouse tomatoes by the application of excess potassium. It resulted in a high potassium content in both upper and lower leaves, but the Mg was not depressed. Ferrari and Sluismans (1955) made the important observations that not only did a high concentration of K-ions in the soil depress Mg-uptake, but also that a higher concentration of Mg within the plant was required to eliminate Mg-deficiency symptoms when the internal concentration of the K-ions was at a high level. An excess of potassium in the nutrient solution is apparently frequently the cause of the occurrence of magnesium deficiency under natural conditions.

#### Soil temperature

Lingle and Davis (1958) found that the concentration of the nutrient elements in tomato seedlings increased with increased root temperatures except that calcium and magnesium concentrations tended to decrease at high temperatures. The magnesium uptake in tomatoes increased with an increase in soil temperature from 50-55 to 70-75 F (10-12.8 to 21.1-23.9 C) and then remained relatively the same at 80-85 F (26.7-29.4 C). Magnesium concentration had apparently stabilized at a point below the highest temperature. However, potassium concentration increased over the entire range of temperatures from



50-55 to 80-85 F. Del Valle and Harmon (1967) indicate that turnip growth and mineral absorption are influenced by soil temperature.

Optimum soil temperatures for growth of tops was higher than for growth of roots. The mineral percentage tended to increase in the roots with increased soil temperature from 45 to 95 F (7.2 to 35 C). In the tops the mineral percentage increased to an optimum temperature range after which it started decreasing. The total mineral uptake in the roots and tops was mainly influenced by the amount of growth. The uptake of magnesium for turnips was largest at 95 F (35 C) for roots from 65 to 75 F (18.3 to 29.4 C) for tops. There is a fall in magnesium uptake with further increase in the temperature to 85 F (29.4 C) in tops. The effect of temperature on mineral concentration in the tops differs from that of the roots, in that it increased in tops to a maximum then decreased as temperature increased whereas in the roots the mineral concentration increased more or less regularly from 45 to 95 F (7.2 to 35 C). Kabu and Toop (1970b) found that high potassium fertilization and high soil temperatures can act together in aggravating the problem of magnesium deficiency. Under a low level of potassium fertilization (4 meq/l) the magnesium content of the plants increased with increase in substrate temperature from 55 to 75 F (12.8 to 23.9 C). At the highest temperature (85 F) (29.4 C) the increase was very little. Under the high substrate potassium (12 meq/l) magnesium content increased with increased soil temperature from 55 to 75 F (12.8 to 23.9). Magnesium uptake was decreased with further increase in the temperature to 85 F (29.4 C).

The potassium content of the plants under the low level of





substrate potassium (4 meq/l) tended to increase as temperature was increased from 55 to 75 F (12.8 to 23.9 C) (Kabu, Toop 1970b). Further increase in temperature (85 F) resulted in an apparent depression in potassium uptake. However under the high substrate level of potassium, the potassium content of the plants at various temperatures did not show any consistent trends. Cannel et al. (1963) did not get a significant effect upon the uptake of magnesium in tomatoes over a soil temperature range of 54 to 95 F (12.2 to 35.6 C). However, potassium increased with the increase in temperature from 54 to 82 F (12.2 to 27.8 C). Further increase in temperature 96 F resulted in a depression in potassium uptake.

#### Light intensity

Among the essential environmental factors affecting the growth and survival of plants on earth, light must be regarded as a major one. Light provides the energy necessary to control the growth and development of horticultural plants.

Ward (1957a) studied the effects of light upon the nutrition of normal and potassium-deficient wheat seedlings growing under growth-chamber conditions. He found that any restriction of light intensity or duration resulted in higher levels of potassium in the plants, when potassium was available. Levels of calcium and magnesium uptake were not directly related to illumination.

As reviewed by Treshaw (1970), Farmer found that as light intensities were reduced from 1700 to 500 fc, aspen plant height diminished correspondingly when temperatures of 24 C (75 F) during



the day and 22 C (72 F) at night were provided. Yet there was no significant height difference when plants were grown at only slightly lower temperatures of 21 C (70 F) during the day and 19 C (68 F) at night. Went (1957) found that heaviest production of the tomato cultivar, Michigan State Forcing, was obtained with a 23 C (73.4 F) day temperature and a 12 C (54 F) night temperature. He further pointed out that an optimum photoperiod and light level was essential to achieve these yields. Went showed that tomato plants could use 16 hours of light at photosynthetic saturation (1000 fc of daylight or white fluorescent light) and that these plants produced about double the dry weight of those at equal irradiation in an 8 hour photoperiod. Kedar and Retig (1968) studied the effect of daylight filtered through plastic materials of varying spectral transmission characteristics on stem elongation of normal and dwarf tomato plants. They found that a decrease in light intensity increased internodal length of both types of plants. As reviewed by Bickford (1972), Canham reported that one of the most important applications of supplemental lighting in England and Europe is in the growing of tomato plants. Supplemental light is most often used on plants sown in November or early December. The use of 300 watt-hours per square foot per day for a period of three weeks resulted in plants that flowered from 10 to 14 days earlier than unlighted plants.

Marr and Hillyer (1968) showed that a reduction of light intensity in the field and in the greenhouse affected the yield and shape of fruit produced. Decreased light intensity reduced yields and increased the percentage of misshapen fruit compared to non-shaded plants. Moe



(1972) studied the interrelated effects of temperature, day length and light intensity on growth and flowering of roses. He found that the rate of shoot growth was stimulated by long days and high temperatures. The final length of shoots at flowering was significantly longer with 16 hour days than with shorter days, whereas increased temperature and light intensity decreased shoot length. Growth of the uppermost internodes was the most sensitive to daylength, temperature and light intensity.

Winsor et al. (1965) investigated the effects of magnesium deficiency on tomatoes at two levels of potassium over a period of years. The data showed that there was a significant yield response with magnesium applications on magnesium deficient tomato plants in only one out of four years, but, that one year coincided with a particularly sunny season. They suspected some relationship to exist between magnesium deficiency and light intensity. Chlorosis has often been observed to be more severe in greenhouses on plants adjacent to the glass. Kabu and Toop (1970c) noted that under high light intensity there was a trend toward less magnesium uptake than under low light conditions. But, differences were not consistent. There was also a trend toward higher potassium content in indicator leaf tissue with lower light intensity.

Little research has been conducted on the influence of light intensity in combination with soil temperature on tomato growth, hence the experiments were designed to determine magnesium deficiency conditions in various ways.



## Materials and Methods

### Experiment 1

The influence of "soil" temperature and potassium fertilization on the growth and the uptake of major cations by tomato seedlings.

The studies reported herein were conducted in nutrition culture experiments using perlite as a growth medium.

### "Soil" temperature

Four water tanks with mechanical temperature controls and each having eight holes large enough for the insertion of 25 cm pots up to the rim were installed in the greenhouse. The temperature of water in the four tanks was set at 12.8 C (55 F), 18.3 C (65 F), 23.9 C (75 F) and 29.4 C (85 F) respectively and maintained within a range of  $\pm 1$  C.

### Cultivar

Seeds of *Lycopersicon esculentum* Mill. cv. Michigan Ohio Hybrid which is a vigorous tomato cultivar producing medium size fruit were obtained from Stokes Seeds Limited, St. Catherines, Ontario. Thirty-two tomato plants were grown in individual 20 cm plastic pots. Four seeds were sown per pot and allowed to germinate in the perlite moistened only with distilled water. Immediately after emergence the plants were thinned to one plant per pot and each pot was fitted into a 25 cm plastic pot having drainage holes plugged by rubber stoppers of appropriate size. Eight plants in as many pots were raised under each of the four substrate temperatures of 12.8, 18.3, 23.9 and 29.4 C.





### Nutrition

The nitrate-type standard nutrient solutions as used at Long Ashton (Hewitt, E. J. 1966) including the minor elements as per the recommendations of Hoagland and Arnon (Hoagland, D. R. 1950) were prepared with variations in the potassium treatments. The levels for potassium were 4 meq and 12 meq per liter of nutrient solution. Half of the plants under each substrate root temperature received potassium at the rate of 4 meq per liter of nutrient solution, the other half received it at 12 meq per liter. The plants were fed weekly and watered as needed with distilled water. Two potassium treatments were applied as a simple factorial at the different "soil" temperatures. Each treatment was replicated four times. The pH of the nutrient solutions was  $5.6 \pm 0.1$ .

### Plant growth

Plant growth as influenced by the various treatments was assessed on the basis of dry weight production, height of plants at time of harvest and date when first flower was produced. Plants were harvested eleven weeks after emergence of the seedlings and separated into roots, stems and leaves. These were washed and dried in a forced-draft oven at 70 C. The plant materials were weighed and the average weight per plant calculated and subjected to analysis of variance by the method outlined by Steel (1960) and Cochran and Cox (1966). The average of four replications was recorded for each of the eight treatments.

### Mineral content

Each dried material was ground in a Wiley Mill to pass a 60 mesh screen. The ground sample was homogenized by means of thorough mixing.



A weighed quantity (1 gr) was ashed in a muffle furnace and the minerals extracted according to the procedure outlined by Ward and Johnston (1962). The extracts were analysed for calcium, magnesium and potassium on a Perkin Elmer Model 303 Atomic Absorption Spectrophotometer according to the procedure outlined by Isaac and Kerber (1971). The spectrophotometer was set and operated as per the directions supplied with the instrument. Standard solutions with concentrations of 0.0 (blank), 0.1, 0.25, 0.50, 0.75 and 1.00 parts per million for magnesium and 0.0 (blank), 0.5, 1, 2.5, 7.5 and 10 parts per million for calcium and potassium were used for plotting the standard curves each time samples were analysed. The standard solutions of the above concentrations were prepared from the certified atomic absorption standard reference solutions for the respective elements supplied by the Fisher Scientific Co., Chemical Manufacturing Division, Fair Lawn, New Jersey, U.S.A.

The plant tissue extracts were diluted with known volumes of distilled water so that the concentrations of the resulting solutions fell within the concentration range of the standard solutions. From the values obtained in terms of parts per million of the element in the diluted solution, the original concentration as percentage of dry weight was calculated. The average of four replications is reported as the concentration of the particular element in the part of the plant under investigation. The data were subjected to analysis of variance and Duncan's multiple-range test. (Steel 1960).



## Experiment II

Influence of light intensity in combination with various 'soil' temperatures and substrate potassium levels on the uptake of major cations by tomato plants.

The purpose of this experiment was to determine the effects of various soil temperatures in combination with two levels of light intensity and two levels of substrate potassium on the growth and ion uptake of greenhouse tomatoes grown in a growth chamber for 11 weeks.

Seeds of tomato, cultivar Michigan-Ohio Hybrid were grown in perlite in plastic containers in a growth chamber. Conditions in the chamber were maintained at 70 F (21.1 C). Light was supplied by cool white fluorescent tubes and the photoperiod was controlled by an electric timer.

The plants were grown under conditions of constant photoperiod, 16 hours, but with light intensity of 750 and 1500 foot candles.

Three water tanks with mechanical temperature controls were installed in the growth chamber. The water temperature of the tanks was set at 12.8, 23.9 and 29.4 C, respectively, and maintained within a range of  $\pm 1$  C. Twelve individual plants were raised under each of the three root-medium temperatures. The plants were watered as needed with distilled water and fed weekly with nutrient solution. A nitrate type standard nutrient solution as used at Long Ashton, including minor elements according to recommendations of Hoagland and Arnon was prepared with variations in potassium levels as required by the two potassium treatments (4 meq/liter and 12 meq/liter).





In each of the three water tanks (3 temperature treatments) plants were grown under two levels of light and two levels of substrate potassium for a total of twelve treatments. Each treatment was replicated three times. Two potassium and two light intensity treatments were applied as a factorial design on the different "soil" temperatures. Low light intensity was achieved by shading with layers of cheesecloth.

The plants were harvested 11 weeks after emergence at a stage of growth when the requirement for mineral nutrients is presumably high. The harvested plants were weighed, dried at 70 C in a forced-air oven. The samples were reweighed and ground for subsequent chemical analysis as described in experiment 1. The dried tissue was ashed at 550 C for four hours. A hydrochloric acid extract of the ash was prepared and analysed for mineral constituents by methods outlined by Ward (1962).

The plant tissue was analysed for potassium, calcium and magnesium within leaves and stems as described in Experiment 1. The flowering date was recorded for each treatment. The plant height was measured and recorded every week after emergence. At the end of the experimental period the plant height, stem-thickness, pH of the substrate and the length of fully elongated internodes were measured. Thus, the upper 3-4 internodes were not taken into account. The data were subjected to analysis of variance and Duncan's multiple range test. (Steel 1960).



## Results

Experiment 1. Influence of substrate temperature and potassium fertilization on plant growth and the uptake of major cations by tomato plants

### A. Influence of substrate temperature and potassium fertilization on tomato plant growth

Significant differences in height were recorded for tomato plants grown under 2 levels of potassium fertilization and 4 substrate temperatures 11 weeks after emergence (Table 1).

Under the low level of potassium (4 meq/liter) the height of the plants increased with increase in substrate temperature up to 23.9 C. At the highest temperature (29.4 C) the height was decreased. Under the high substrate potassium (12 meq/liter) the same pattern was evident with the tallest plants at the middle range of temperatures.

Analysis of variance indicated that the substrate temperature had a highly significant ( $p = 0.01$ ) influence and the potassium level had a significant ( $p = 0.05$ ) influence on the plant height. However, no interaction effect of those two variables was evident.

Statistical analysis indicated that there were no significant differences in the height of the first flower cluster on any tomato plants regardless of treatment (Table 2).

The date on which the first flower buds opened was recorded for plants in each treatment. Under low potassium nutrition, the flowers bloomed an average of 62 days after emergence at 12.8 and 18.3 C, 55 days at 23.9 C and 56 days at 29.4 C. Under high potassium nutrition, the flowers bloomed 57 days after emergence at 12.8 and 18.3 C, 55 days



Table 1. Height of tomato plants grown under 2 potassium and 3 temperature substrate levels

Treatment Substrate temperature (C)	<u>Height of tomato plants (Cm)</u>	
	4 meq K <sup>+</sup> /liter	12 meq K <sup>+</sup> /liter
12.8	* 109.3 a	109.8 a
18.3	113.0 ab	127.9 c
23.9	120.3 bc	125.8 c
29.4	110.5 ab	113.5 ab

\*Within or between columns figures not followed by the same letter are significantly different from each other ( $p = 0.05$ ) according to Duncan's multiple-range test.



Table 2. The height of the first flower cluster of tomato plants under 2 potassium and 4 temperature substrate levels

Treatment Substrate temperature (C)	<u>Height of 1st flower cluster (Cm)</u>	
	4 meq K <sup>+</sup> /liter	12 meq K <sup>+</sup> /liter
12.8	* 76.5 a	64.8 a
18.3	72.3 a	72.3 a
23.9	72.3 a	72.5 a
29.4	66.8 a	69.8 a

\*Within or between columns figures followed by the same letter are not significantly different from each other ( $p = 0.05$ ) according to Duncan's multiple-range test.





at 23.9 C, and 56 days at 29.4 C. Although statistical analyses were not made the difference of 5 days between the two potassium treatments at the two lower temperature regimes is of practical significance.

Maximum growth, measured on a dry weight basis, was obtained under the high level of potassium at root-medium temperatures of 18.3 and 23.9 C (Table 3). The dry weight of both leaves and stems followed much the same pattern as that of the entire plant but the dry weight of roots tended to decrease with increase in temperature over the entire range. In all instances dry weights were greater at the higher level of substrate potassium but differences were not always statistically significant.

The analysis of variance indicated that the substrate temperature and the potassium level had a highly significant ( $p = 0.01$ ) influence on the dry weight production of entire plants. The dry weights of both leaves ( $p = 0.01$ ) and stems ( $p = 0.05$ ) considered separately were influenced by the substrate temperature and the potassium level as was the entire plant but only the substrate temperature had a highly significant ( $p = 0.01$ ) influence on the dry weight of roots. However, no interaction effect of those two variables was evident except on the dry weight of the stems. Both the substrate temperature and its interaction with the potassium level did affect the dry weight of stems. Statistical analysis revealed a significant influence of "soil" temperature on the dry weight production under high potassium levels at substrate temperature of 18.3 and 23.9 C than at substrate temperature of 12.8 and 29.4 C for the stems, leaves and the plants as a whole.



Table 3. Average dry weight of tomato plants grown under 2 potassium and 4 temperature substrate levels

Treatment		Dry weight per plant (g)	
Substrate temperature (C)		4 meq K <sup>+</sup> /liter	12 meq K <sup>+</sup> /liter
Leaves	12.8	*10.68 ab	12.83 c
	18.3	11.15 ab	13.88 cd
	23.9	13.24 cd	14.70 d
	29.4	10.56 a	12.25 bc
Stems	12.8	5.45 a	6.14 ab
	18.3	6.57 b	8.95 d
	23.9	7.41 c	9.27 d
	29.4	5.42 a	6.67 b
Roots	12.8	2.21 bc	2.64 c
	18.3	1.96 ab	2.24 bc
	23.9	1.68 ab	1.70 ab
	29.4	1.44 a	1.60 a
Whole plants	12.8	18.34 ab	21.60 cd
	18.3	19.68 bc	25.07 e
	23.9	22.32 d	25.66 e
	29.4	17.42 a	20.52 bcd

\*Figures not followed by the same letter, within or between columns within each group (i.e. leaves, stems, roots, whole plants) are significantly different from each other ( $p = 0.05$ ) according to Duncan's multiple-range test.



B. Influence of substrate temperature and potassium fertilization on the mineral content of tomato plants

With regard to the mineral content of the plants under the various treatments the entire plants were harvested and the leaves, stems and roots analyzed separately for total magnesium, potassium and calcium content.

1. Magnesium

Magnesium content was tabulated both in terms of the average total magnesium content per plant (Table 4) and as percent of dry weight (Table 5).

Under the low level of substrate potassium (4 meq/liter) the magnesium content of the aerial portions of the plants appeared to increase with increase in substrate temperatures (Table 4). On the other hand at the high level of substrate potassium (12 meq/liter) the magnesium content of the aerial portions of the plants increased with increase in substrate temperature only up to 23.9 C after which it dropped. The magnesium content of the roots tended to decrease with increase in substrate temperature under both levels of substrate potassium.

The magnesium content of the plants expressed as percent of dry weight did not show any consistent trends and appears not to be much affected by substrate temperatures under either level of substrate potassium. However, under the high level of substrate potassium there was a tendency for the magnesium content as percent of dry weight of the aerial portions of the plants to increase with increase in substrate temperature up to 23.9 C after which it dropped. The magnesium content of the roots as percent of dry weight appeared to





Table 4. Total  $Mg^{++}$  in the vegetative organs of tomato plants grown under 2 potassium and 4 temperature substrate levels

Treatment		Average total $Mg^{++}$ content per plant (mg)	
Substrate temperature (C)		4 meq $K^+$ /liter	12 meq $K^+$ /liter
Leaves	12.8	*41.65 a	36.57 a
	18.3	39.58 a	45.80 a
	23.9	39.72 a	58.07 b
	29.4	44.35 a	34.91 a
Stems	12.8	12.81 ab	11.67 a
	18.3	16.43 c	16.56 c
	23.9	15.56 bc	16.22 c
	29.4	17.07 c	14.01 abc
Roots	12.8	3.32 ab	5.15 b
	18.3	3.33 ab	4.03 ab
	23.9	2.94 ab	2.55 a
	29.4	2.81 ab	2.48 a
Aerial Portion (leaves & stems)	12.8	54.46 a	48.24 a
	18.3	56.01 a	62.36 ab
	23.9	55.28 a	74.29 b
	29.4	61.42 ab	48.92 a
Whole plants	12.8	57.78 ab	53.39 ab
	18.3	59.34 ab	66.39 bc
	23.9	58.22 ab	76.84 c
	29.4	64.23 abc	51.40 a

\*Figures not followed by the same letter, within or between columns within each group (i.e., leaves, stems, roots, aerial portions and whole plants) are significantly different from each other ( $p = 0.05$ ) according to Duncan's multiple-range test.



Table 5. Magnesium content as percent of dry weight in the vegetative organs of tomato plants grown under 2 potassium and 4 temperature substrate levels

Treatment		Average Mg <sup>++</sup> content per plant (Percent dry weight)	
		4 meq K <sup>+</sup> /liter	12 meq K <sup>+</sup> /liter
Leaves	12.8	* 0.390 bc	0.285 a
	18.3	0.355 abc	0.330 abc
	23.9	0.300 ab	0.395 bc
	29.4	0.420 C	0.285 a
Stems	12.8	0.235 bc	0.190 ab
	18.3	0.250 c	0.185 ab
	23.9	0.210 abc	0.175 a
	29.4	0.315 d	0.210 abc
Roots	12.8	0.150 a	0.195 b
	18.3	0.170 ab	0.180 ab
	23.9	0.175 ab	0.150 a
	29.4	0.195 b	0.155 a
Aerial Portions (leaves & stems)	12.8	0.340 bc	0.255 a
	18.3	0.315 abc	0.275 ab
	23.9	0.270 ab	0.315 abc
	29.4	0.385 c	0.255 a
Whole plants	12.8	0.325 bc	0.245 a
	18.3	0.300 abc	0.265 ab
	23.9	0.260 ab	0.295 abc
	29.4	0.370 c	0.255 ab

\*Figures not followed by the same letter, within or between columns within each group (i.e., leaves, stems, roots, aerial portions and whole plants) are significantly different from each other ( $p = 0.05$ ) according to Duncan's multiple-range test.



increase with increase in substrate temperature under the low level of substrate potassium but showed the opposite relations under the high level of substrate potassium. However, differences were not always statistically significant. As far as aerial portions of the plants are concerned the  $Mg^{++}$  as percent of dry weight reached its peak at 29.4 C for the low level of substrate  $K^+$  and at 23.9 C for the high level of substrate  $K^+$ .

The analysis of variance indicated that the potassium level had a highly significant ( $p = 0.01$ ) influence and the substrate temperature had a significant ( $p = 0.05$ ) influence on the magnesium content as percent of dry weight but of stems only. Interaction of the substrate temperature and the potassium level appeared to affect the uptake of magnesium but not its distribution, at least with respect to stems.

## 2. Potassium

Potassium content was tabulated both in terms of the average total potassium content per plant (Table 6) and as percent of dry weight (Table 7).

The potassium content of the aerial portions of the plants was numerically greatest at 23.9 C under low level of substrate potassium and at 18.3 C under high level of substrate potassium. The potassium content of the roots decreased with increase in substrate temperature beyond 18.3 C under both levels of substrate potassium (Table 6).

The potassium content of the plants expressed as percent of dry weight did not show any consistent trends. However, at the lower level of substrate  $K^+$  the uptake of  $K^+$  was significantly greater at



Table 6. Total potassium in the vegetative organs of tomato plants under 2 potassium and 4 temperature substrate levels

Treatment		Average total K <sup>+</sup> per plant (g)	
Substrate temperature (C)		4 meq K <sup>+</sup> /liter	12 meq K <sup>+</sup> /liter
Leaves	12.8	*0.299 a	0.085 d
	18.3	0.323 b	1.006 e
	23.9	0.344 b	1.036 f
	29.4	0.306 a	0.870 c
Stems	12.8	0.185 bc	0.319 d
	18.3	0.161 a	0.488 f
	23.9	0.204 c	0.409 e
	29.4	0.171 ab	0.340 d
Roots	12.8	0.020 c	0.084 g
	18.3	0.017 bc	0.088 f
	23.9	0.014 ab	0.050 e
	29.4	0.012 a	0.041 d
Aerial Portions (leaves & stems)	12.8	0.484 a	1.204 b
	18.3	0.484 a	1.494 c
	23.9	0.548 a	1.445 c
	29.4	0.477 a	1.210 b
Whole plants	12.8	0.504 a	1.288 d
	18.3	0.507 a	1.582 f
	23.9	0.562 b	1.495 e
	29.4	0.489 a	1.251 c

\*Figures not followed by the same letter, within or between columns within each group (i.e., leaves, stems, roots, aerial portions and whole plants) are significantly different from each other ( $p = 0.05$ ) according to Duncan's multiple-range test.





Table 7. Potassium content as percent of dry weight in the vegetative organs of tomato plants under 2 potassium and 4 temperature substrate levels

Treatment		Average K <sup>+</sup> content per plant (Percent dry weight)	
		4 meq K <sup>+</sup> /liter	12 meq K <sup>+</sup> /liter
substrate temperature (C)			
Leaves	12.8	* 2.800 b	6.900 d
	18.3	2.800 b	7.250 f
	23.9	2.600 a	7.150 e
	29.4	2.900 c	7.100 e
Stems	12.8	3.400 b	5.200 de
	18.3	2.450 a	5.450 e
	23.9	2.750 a	4.400 c
	29.4	3.150 b	5.100 d
Roots	12.8	0.900 a	3.200 d
	18.3	0.850 a	3.950 e
	23.9	0.850 a	2.950 c
	29.4	0.850 a	2.550 b
Aerial Portions (leaves & stems)	12.8	3.000 b	6.355 d
	18.3	2.730 a	6.540 e
	23.9	2.650 a	6.030 c
	29.4	2.985 b	6.400 de
Whole plants	12.8	2.750 b	5.965 cd
	18.3	2.550 a	6.305 e
	23.9	2.525 a	5.825 cd
	29.4	2.810 b	6.095 d

\*Figures not followed by the same letter, within or between columns within each group (i.e., leaves, stems, roots, aerial portions and whole plants) are significantly different from each other ( $p = 0.05$ ) according to Duncan's multiple-range test.



both the lowest and the highest temperatures. At the higher level of substrate  $K^+$  uptake was highest at 18.3 C. As one expects, potassium uptake was consistently higher at the higher level of substrate  $K^+$  (Table 7).

Analysis of variance indicated that the substrate potassium level had a highly significant ( $p = 0.01$ ) influence on the potassium content of the entire plants. Substrate potassium level and its interaction with substrate temperature also appeared to affect the potassium content of the entire plants.

### 3. Calcium

Calcium content was tabulated both in terms of the average total calcium content per plant (Table 8) and as percent of dry weight (Table 9).

Under the low level of substrate potassium the calcium content of the aerial portions of the plants tended to reach a peak at substrate temperature of 23.9 C. At the highest temperature (29.4 C) the calcium content was decreased (Table 8). On the other hand, under the high level of substrate potassium the calcium content of the aerial portions of the plants was highest at substrate temperature of 18.3 C. At temperatures above this the calcium content of the aerial portions of the plants progressively decreased. The calcium content of the roots tended to decrease with increase in substrate temperature over the entire range of temperatures used under both levels of substrate potassium.

Expressed as percent of dry weight, the calcium content of the aerial portions of the plants appeared to decrease moderately with increase in substrate temperature under the low level of substrate



Table 8. Total calcium in the vegetative organs of tomato plants  
under 2 potassium and 4 temperature substrate levels

Treatment		Average total $\text{Ca}^{++}$ content per plant (g)	
substrate temperature (C)		4 meq $\text{K}^+$ /liter	12 meq $\text{K}^+$ /liter
Leaves	12.8	*0.336 bc	0.257 ab
	18.3	0.290 abc	0.326 bc
	23.9	0.357 c	0.294 abc
	29.4	0.243 ab	0.208 a
Stems	12.8	0.095 bc	0.074 a
	18.3	0.108 cd	0.130 e
	23.9	0.119 de	0.097 bc
	29.4	0.081 ab	0.087 ab
Roots	12.8	0.050 b	0.065 c
	18.3	0.050 b	0.054 bc
	23.9	0.035 a	0.031 a
	29.4	0.024 a	0.032 a
Aerial Portions (leaves & stems)	12.8	0.431 c	0.331 ab
	18.3	0.398 bc	0.456 c
	23.9	0.476 c	0.391 abc
	29.4	0.324 ab	0.295 a
Whole plants	12.8	0.481 cd	0.396 abc
	18.3	0.448 bcd	0.510 d
	23.9	0.511 d	0.422 abcd
	29.4	0.348 ab	0.327 a

\*Figures not followed by the same letter, within or between columns within each group (i.e., leaves, stems, roots, aerial portions and whole plants) are significantly different from each other ( $p = 0.05$ ) according to Duncan's multiple-range test.





Table 9. Calcium content as percent of dry weight in the vegetative organs of tomato plants under 2 potassium and 4 temperature substrate levels

Treatment		Average $\text{Ca}^{++}$ content per plant (percent dry weight)	
		4 meq $\text{K}^+$ /liter	12 meq $\text{K}^+$ /liter
Leaves	12.8	* 3.15 a	2.00 ab
	18.3	2.60 bc	2.35 ab
	23.9	2.70 bc	2.00 ab
	29.4	2.30 ab	1.70 a
Stems	12.8	1.75 d	1.20 ab
	18.3	1.65 cd	1.45 abcd
	23.9	1.60 bcd	1.05 a
	29.4	1.50 bcd	1.30 abc
Roots	12.8	2.25 abc	2.45 c
	18.3	2.55 c	2.40 bc
	23.9	2.10 abc	1.80 ab
	29.4	1.65 a	2.00 abc
Aerial Portions (leaves & stems)	12.8	2.680 e	1.750 a
	18.3	2.265 bc	1.995 ab
	23.9	2.310 bc	1.635 a
	29.4	2.030 ab	1.560 a
Whole Plants	12.8	2.625 c	1.830 a
	18.3	2.290 bc	2.035 ab
	23.9	2.290 bc	1.650 a
	29.4	1.995 ab	1.590 a

\*Figures not followed by the same letter within or between columns within each group (i.e. leaves, stems, roots, aerial portions and whole plants) are significantly different from each other ( $p = 0.05$ ) according to Duncans' multiple-range test.



potassium (Table 9). Under the high substrate potassium the same pattern was evident except that the calcium content of the aerial parts of the plants tended to be higher at 18.3 C.

Analysis of variance indicated that the potassium level had a highly significant ( $p = 0.01$ ) influence on the calcium content of the leaves, stems and the plants taken as a whole. The substrate temperature had a significant influence ( $p = 0.05$ ) on the calcium content of the stems but no significant effect on the calcium content of the roots. There was no interaction effect of those two variables on the calcium content of the plants.



Experiment II. Influence of light intensity, substrate temperature and potassium fertilization on plant growth and the uptake of major cations by tomato plants

A. Influence of light intensity, substrate temperature and potassium fertilization on tomato plant growth

For the first 6 to 7 weeks from germination there was little difference in the height of the plants regardless of treatments. From 7 weeks after germination until harvest (11 weeks) differences in height due to treatment were evident (Fig. 1, 2 and 3). Under the high level of potassium, light intensity had much less effect on plant height than it did under the low level of substrate potassium at the 12.8 C substrate temperature (Fig. 1). As the experiment progressed, the difference in height between plants of the two light treatments became greater under the low potassium level but became slightly less under the high potassium level. At the higher light intensity the plants were taller and potassium substrate level appeared to have less influence than was the case with plants growing under the lower light intensity where high substrate potassium appeared to compensate for reduced light to some extent.

As substrate temperature was increased the plants receiving the higher light intensity tended to be shorter than those receiving the lower light intensity under each level of substrate potassium. At 23.9 C substrate temperature the difference in height between partially shaded and unshaded plants was greater under the low substrate potassium level than under the high potassium level.

High potassium increased the height of plants under both levels



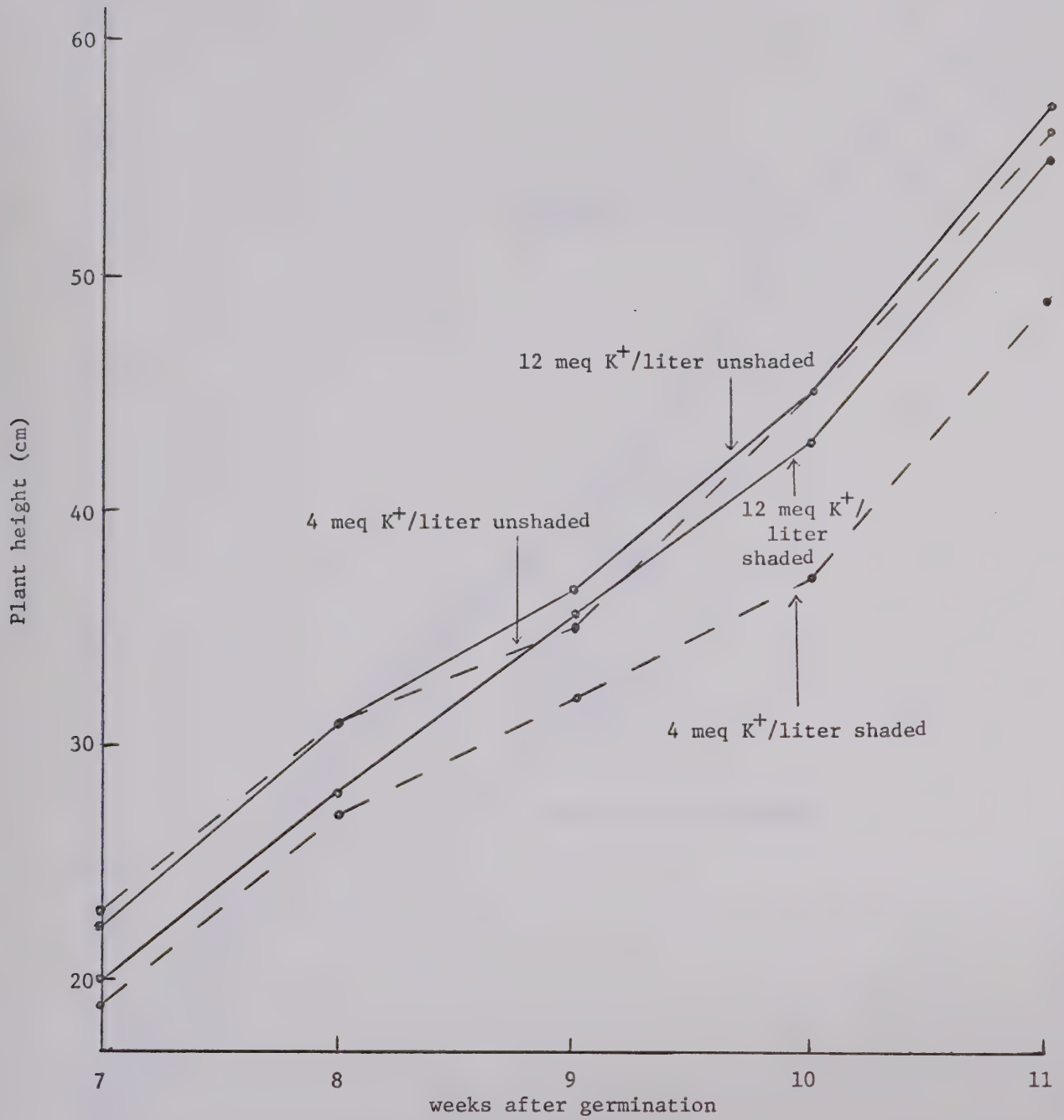


Figure 1. The effect of light intensity and potassium levels on elongation of tomato plants at substrate temperature of 12.8 C





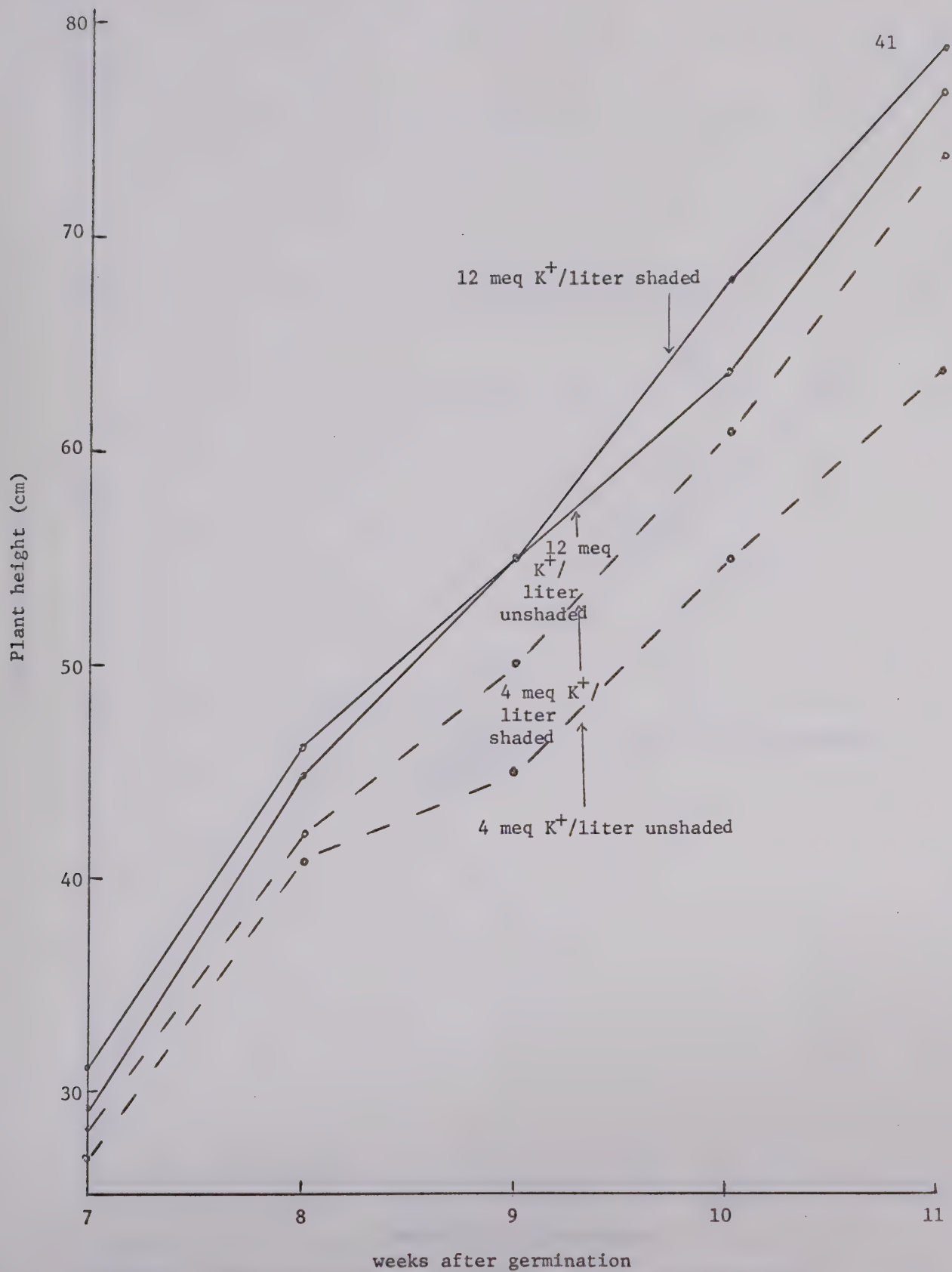


Figure 2. The effect of light intensity and potassium levels on elongation of tomato plants at substrate temperature of 23.9 C



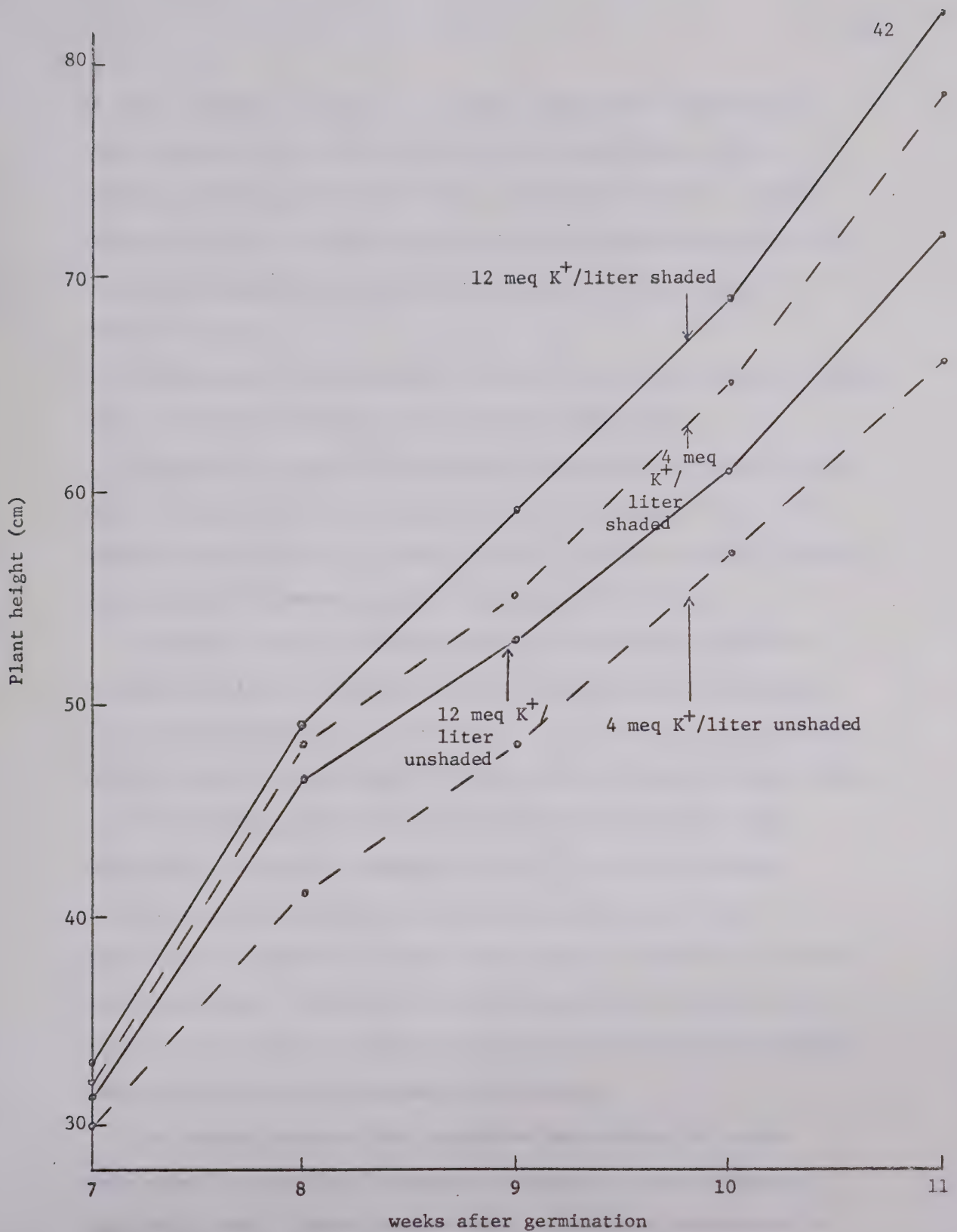


Figure 3. The effect of light intensity and potassium levels on elongation of tomato plants at substrate temperature of 29.4 C



of light intensity. (Fig. 2). At 29.4 C substrate temperature the light appeared to have the major effect on plant height with all partially shaded plants being taller than unshaded plants regardless of potassium level. The differences in height between plants of the two light treatments were great for both low and high potassium levels. (Fig. 3).

At the end of the experimental period, the average height of plants under the various treatments was tabulated (Table 10).

Under the low level of potassium (4 meq/liter) the height of the plants increased with increase in substrate temperature under both levels of light intensity. Under the high level of substrate potassium (12 meq/liter) the same pattern was evident. (Table 10).

Analysis of variance indicated that the substrate temperature, the potassium level and light intensity all had a highly significant ( $p = 0.01$ ) influence on the plant height. The substrate temperature and its interaction with light intensity also affected the plant height.

The elongation of internodes of tomato plants under 2 light intensities, 3 substrate temperatures and 2 levels of potassium fertilization were recorded 11 weeks after germination (Table 11). The number of internodes on each plant stalk was found to be 13 regardless of treatment. Therefore the differences in the heights of the plants of the various treatments were due to differences in internode length rather than in the number of internodes.

The average length of the internodes was similar for plants grown under both levels of substrate potassium at each substrate temperature level. Under the low level of potassium differences in





Table 10. Height of tomato plants grown under 2 potassium and 3 temperature substrate levels and 2 levels of light intensity

Treatment		Height of tomato plants 11 weeks after germination (cm)	
Substrate temperature (C)	Light intensity (f.c.)	4 meq K <sup>+</sup> /liter	12 meq K <sup>+</sup> /liter
12.8	750	* 49.00 a	55.00 ab
	1500	56.33 abc	57.00 abc
23.9	750	74.00 efg	79.33 fg
	1500	63.67 bcd	76.67 fg
29.4	750	78.67 fg	83.00 g
	1500	65.67 cde	71.67 efg

\*Within or between columns figures not followed by the same letter are significantly different from each other ( $p = 0.05$ ) according to Duncan's multiple-range test.



Table 11. Elongation of internodes of tomato plants grown under 2 potassium and 3 temperature substrate levels and 2 levels of light intensity

Treatment		<u>length of internodes (mm)</u>	
Substrate temperature (C)	Light intensity (f.c.)	4 meq K <sup>+</sup> /liter	12 meq K <sup>+</sup> /liter
<u>*older internodes</u>			
12.8	750	*** 43.3 ab	39.5 ab
	1500	40.8 ab	37.5 a
23.9	750	55.0 def	60.8 f
	1500	48.3 bcd	43.8 abc
29.4	750	57.9 ef	61.7 f
	1500	50.8 cde	46.3 abcd
<u>**younger internodes</u>			
12.8	750	55.4 abc	53.3 ab
	1500	54.6 abc	52.8 a
23.9	750	63.3 cd	72.1 ef
	1500	60.7 bcd	58.5 abcd
29.4	750	67.0 def	74.3 f
	1500	64.7 de	61.9 bcd

\*Internodes up to 7 from base of the stalk.

\*\*Internodes 8 to 13.

\*\*\*Figures not followed by the same letter, within or between columns within each group \*i.e. older internodes, younger internodes) are significantly different from each other ( $p = 0.05$ ) according to Duncan's multiple-range test.



internode length were slightly greater at the low light intensity than at the higher light intensity at each substrate temperatures but differences were not statistically significant. Under the high level of potassium, internode length was much greater at the low light intensity except at the lowest substrate temperature.

The effect of light intensity on internode length was greater under the high level of potassium than under the low level of potassium with increase in substrate temperatures.

Analysis of variance confirmed that there was a highly significant effect of substrate temperature and light intensity on internode length for both older and younger internodes. Potassium nutrition and its interaction with light intensity, as well as substrate temperature and its interaction with light intensity had an effect on the elongation of older internodes whereas only potassium nutrition and its interaction with light intensity affected the younger internodes.

Significant differences in height of the first flower cluster were found for tomato plants grown at 2 levels of potassium and 3 substrate temperatures and 2 light intensities (Table 12).

Under low light intensity and higher substrate temperatures (23.9 and 29.4 C) the flower cluster height was greater than that of other treatments. Under both levels of substrate potassium and light intensity the height of the first flower cluster tended to increase with increase in substrate temperature. At the lowest substrate temperature and low light intensity plants under high substrate potassium had flower clusters significantly higher than plants under low substrate potassium. Analysis of variance indicated that the



Table 12. Height of the first flower cluster of tomato plants grown under 2 potassium and 3 temperature substrate levels and 2 levels of light intensity

Treatment		Height of the first flower cluster of tomato plants (cm)	
Substrate temperature (C)	Light intensity (f.c.)	4 meq K <sup>+</sup> /liter	12 meq K <sup>+</sup> /liter
12.8	750	*39.2 a	42.5 bc
	1500	35.3 ab	31.3 a
23.9	750	48.3 cde	55.5 e
	1500	39.0 ab	44.0 bcd
29.4	750	51.7 de	53.7 e
	1500	39.8 abc	38.7 ab

\*Within or between columns figures not followed by the same letter are significantly different from each other ( $p = 0.05$ ) according to Duncan's multiple-range test.





substrate temperature and light intensity had a highly significant ( $p = 0.01$ ) influence on the height of the first flower cluster. However, no interaction effect of the three treatment variables was evident.

The number of days from germination to the opening of the first flower bud was recorded for plants in each treatment (Table 13). Some of the differences between treatments are of practical significance. High potassium levels coupled with higher light intensity and higher substrate temperatures appeared to hasten maturity of the first flower buds. The most significant delay in flowering was attributed to the lowest substrate temperature.

The thickness of tomato plant stems apparently is affected significantly by potassium levels, light intensity and substrate temperature (Table 14).

Analysis of variance indicated that all three of these variables had a highly significant ( $p = 0.01$ ) influence on the stem thickness of the plants. Although no interaction effect of these three variables was indicated by analysis of variance the plants with the thickest stems were those grown under high substrate potassium, the highest temperature level and the higher light level.

Maximum growth, measured on a dry weight basis, was obtained under the high level of potassium and the higher light intensity at a root-medium temperature of 23.9 and 29.4 C (Table 15). The dry weight of both leaves and stems taken separately followed much the same pattern as that of the entire plant. In all instances dry weights were greater at the higher level of substrate potassium and at the higher level of light intensity but differences were not



Table 13. The days to first flower of tomato plants under 2 potassium and 3 temperature substrate levels and 2 levels of light intensity

Treatment		<u>Days to first flower</u>	
Substrate temperature (C)	light intensity (f.c.)	4 meq K <sup>+</sup> /liter	12 meq K <sup>+</sup> /liter
12.8	750	69	63
	1500	56	54
23.9	750	57	57
	1500	53	51
29.4	750	59	58
	1500	52	49



Table 14. The thickness of tomato plant stems grown under 2 potassium and 3 temperature substrate levels and 2 levels of light intensity

Substrate temperature (C)	Treatment		Stem thickness of the plants (mm)	
	Light intensity (f.c.)		4 meq K <sup>+</sup> /liter	12 meq K <sup>+</sup> /liter
12.8	750		* 8.30 a	9.13 b
	1500		9.47 c	10.33 e
23.9	750		10.27 e	10.13 d
	1500		10.13 d	11.27 g
29.4	750		10.17 d	10.50 f
	1500		11.43 h	12.37 i

\*Within or between columns figures followed by the same letter are not significantly different from each other ( $p = 0.05$ ) according to Duncan's multiple-range test.





Table 15. Average dry weight of tomato plants grown under 2 potassium and 3 temperature substrate levels and 2 levels of light intensity

Treatment			Dry weight per plant (g)	
Substrate temperature (C)	Light intensity (f.c.)		4 meq K <sup>+</sup> /liter	12 meq K <sup>+</sup> /liter
Leaves	12.8	750	* 7.76 a	11.13 b
		1500	11.55 b	11.76 b
	23.9	750	13.84 bc	15.55 cd
		1500	15.77 cd	19.80 e
	29.4	750	14.70 bcd	14.76 bcd
		1500	17.56 de	18.82 e
Stems	12.8	750	2.59 a	4.21 ab
		1500	5.65 bc	5.68 bc
	23.9	750	5.85 bc	8.52 def
		1500	7.05 cde	10.73 fg
	29.4	750	6.26 bcd	7.57 cde
		1500	8.74 ef	12.35 g
Whole plants (leaves & stems)	12.8	750	10.36 a	15.34 ab
		1500	17.20 bc	17.34 bc
	23.9	750	19.69 bcd	24.07 de
		1500	22.82 cde	30.53 f
	29.4	750	20.95 cde	22.33 cde
		1500	26.30 ef	31.17 f

\*Figures not followed by the same letter, within or between columns within each group (i.e. leaves, stems, whole plants) are significantly different from each other ( $p = 0.05$ ) according to Duncan's multiple-range test.



always statistically significant.

The analysis of variance indicated that the substrate temperature, light intensity and the potassium level had a highly significant ( $p = 0.01$ ) influence on the dry weight production of the tomato plants. However, no interaction effect of these three variables was evident. The statistical analysis revealed a significant influence of substrate temperature and light intensity on the dry weight production at the higher substrate temperatures (23.9 and 29.4 C).

B. Influence of substrate temperature in combination with light intensity and potassium fertilization on the mineral content of tomato plants

With regard to the mineral content of the plants under various treatments the aerial portions of the plants were harvested and the leaves and stems analyzed separately for total magnesium, potassium and calcium content.

1. Magnesium

Magnesium content was tabulated both in terms of the average total magnesium content per plant (Table 16) and as percent of dry weight (Table 17).

Under the low level of substrate potassium the magnesium content of the plants appeared to increase with increase in substrate temperatures under both levels of light intensity (Table 16). On the other hand under the high level of substrate potassium the magnesium content of the aerial portions of the plants increased with increase in substrate temperature only up to 23.9 C after which it leveled off or dropped for both levels of light intensity.



Table 16. Total  $Mg^{++}$  of tomato plant tops grown under 2 potassium and 3 temperature substrate levels and 2 levels of light intensity

Treatment			Average $Mg^{++}$ content per plant (mg)	
Substrate temperature (C)	Light intensity (f.c.)		4 meq $K^+$ /liter	12 meq $K^+$ /liter
Leaves	12.8	750	*20.80 a	21.40 a
		1500	19.46 a	16.60 a
	23.9	750	33.50 cd	31.60 bcd
		1500	27.08 b	32.50 bcd
	29.4	750	35.56 d	31.73 bcd
		1500	31.54 bcd	30.00 bc
Stems	12.8	750	6.68 a	9.27 ab
		1500	10.38 ab	10.84 abc
	23.9	750	12.22 abc	16.43 c
		1500	14.35 bc	21.82 d
	29.4	750	14.17 bc	14.92 bc
		1500	15.97 bc	22.70 d
Whole plants (leaves & stems)	12.8	750	27.47 a	30.67 a
		1500	29.84 a	27.44 a
	23.9	750	45.72 bc	48.03 bcd
		1500	41.43 b	54.32 d
	29.4	750	50.73 cd	46.65 bcd
		1500	47.52 bcd	52.70 cd

\*Figures not followed by the same letter, within or between columns within each group (i.e. leaves, stems, whole plants) are significantly different from each other ( $p = 0.05$ ) according to Duncan's multiple-range test.



Table 17. Magnesium content as percent of dry weight of tomato plant tops grown under 2 potassium and 3 temperature substrate levels and 2 levels of light intensity

Treatment			Average Mg <sup>++</sup> content per plant (percent of dry weight)	
Substrate temperature (C)	Light intensity (f.c.)		4 meq K <sup>+</sup> /liter	12 meq K <sup>+</sup> /liter
Leaves	12.8	750	* 0.274 f	0.194 bc
		1500	0.168 ab	0.142 a
	23.9	750	0.242 def	0.204 cd
		1500	0.173 abc	0.165 ab
	29.4	750	0.251 ef	0.215 cde
		1500	0.182 abc	0.162 ab
Stems	12.8	750	0.259 d	0.221 bc
		1500	0.184 a	0.193 ab
	23.9	750	0.209 abc	0.196 abc
		1500	0.203 abc	0.205 abc
	29.4	750	0.228 c	0.197 abc
		1500	0.182 a	0.189 ab
Whole plants (leaves & stems)	12.8	750	0.270 e	0.201 bcd
		1500	0.174 ab	0.156 a
	23.9	750	0.232 d	0.201 bcd
		1500	0.182 abc	0.178 abc
	29.4	750	0.244 de	0.209 cd
		1500	0.182 abc	0.172 ab

\*Figures not followed by the same letter, within or between columns within each group (i.e. leaves, stems, whole plants) are significantly different from each other ( $p = 0.05$ ) according to Duncan's multiple-range test.





The magnesium content of the plants expressed as percent of dry weight did not show any consistent trends and few differences between temperature treatments or potassium levels were statistically significant. However significantly more magnesium in proportion to dry weight was found in plants under the low light intensity as compared with the higher light intensity regardless of levels of substrate potassium or substrate temperatures. The magnesium content in relation to the dry weight tended to be greater under the low level of potassium as compared with the higher level of potassium but differences were usually not statistically significant. As far as the higher light intensity is concerned the magnesium content in relation to the dry weight was not related to substrate temperature or substrate potassium.

The analysis of variance indicated that substrate potassium levels and light intensities affected the magnesium content in relation to dry weight of the leaves whereas only light intensity affected this relationship in the stems.

Potassium nutrition and its interaction with light intensity affected this magnesium dry weight ratio in the leaves. On the other hand potassium nutrition and its interaction with light intensity as well as substrate temperature and its interaction with light intensity affected this ratio in the stems.

## 2. Potassium

Potassium content was tabulated both in terms of the average total potassium content per plant (Table 18) and as percent of dry weight (Table 19).

Under both levels of substrate potassium and low light intensity



Table 18. Total potassium content of tomato plant tops grown under 2 potassium and 3 temperature substrate levels and 2 levels of light intensity

Treatment			Average total K <sup>+</sup> per plant (g)	
Substrate temperature (C)	Light intensity (f.c.)		4 meq K <sup>+</sup> /liter	12 meq K <sup>+</sup> /liter
Leaves	12.8	750	0.228 a	0.536 d
		1500	0.206 ab	0.427 cd
	23.9	750	0.365 c	0.789 e
		1500	0.315 abc	0.790 e
	29.4	750	0.358 bc	0.871 e
		1500	0.304 abc	0.715 e
Stems	12.8	750	0.073 a	0.169 c
		1500	0.111 a	0.179 bc
	23.9	750	0.155 b	0.307 de
		1500	0.156 ab	0.344 de
	29.4	750	0.131 b	0.285 e
		1500	0.165 ab	0.356 d
Whole plants (leaves & stems)	12.8	750	0.300 a	0.704 b
		1500	0.317 ab	0.606 b
	23.9	750	0.520 b	1.097 cd
		1500	0.471 b	1.140 cd
	29.4	750	0.489 ab	1.156 c
		1500	0.469 b	1.071 d

\*Figures not followed by the same letter, within or between columns within each group (i.e. leaves, stems, whole plants) are significantly different from each other ( $p = 0.05$ ) according to Duncan's multiple-range test.



Table 19. Potassium content as percent of dry weight of tomato plant tops grown under 2 potassium and 3 temperature substrate levels and 2 levels of light intensity

Treatment			Average K <sup>+</sup> content per plant (Percent of dry weight)	
Substrate temperature (C)	Light intensity (f.c.)		4 meq K <sup>+</sup> /liter	12 meq K <sup>+</sup> /liter
Leaves	12.8	750	* 2.96 c	4.84 e
		1500	1.77 a	3.65 d
	23.9	750	2.64 c	5.13 e
		1500	2.01 ab	4.00 d
	29.4	750	2.45 bc	5.93 f
		1500	1.75 a	3.81 d
Stems	12.8	750	2.87 c	4.10 e
		1500	1.98 a	3.23 cd
	23.9	750	2.65 bc	3.64 de
		1500	2.21 ab	3.20 cd
	29.4	750	2.11 ab	3.76 de
		1500	1.89 a	2.92 c
Whole plants (leaves & stems)	12.8	750	2.93 d	4.64 f
		1500	1.84 a	3.48 e
	23.9	750	2.65 cd	4.61 f
		1500	2.07 ab	3.71 e
	29.4	750	2.35 bc	5.19 g
		1500	1.79 a	3.45 e

\*Figures not followed by the same letter, within or between columns within each group (i.e. leaves, stems, whole plants) are significantly different from each other ( $p = 0.05$ ) according to Duncan's multiple-range test.



the potassium content of the aerial portions of the plants increased with increase in substrate temperature up to 23.9 C after which it leveled off or dropped (Table 18). As one would expect the potassium content was higher in plants growing under the high level of substrate potassium than those under the low level.

Expressed as percent of dry weight the potassium content of the plants was remarkably different under the two light intensities and two potassium levels regardless of root medium temperature (Table 19). Under both levels of substrate potassium the plant potassium content as per cent of dry weight was higher at low light intensity than high light intensity regardless of substrate temperature. The maximum potassium uptake occurred at low light intensity in combination with high substrate temperature under high level of substrate potassium (Table 18 and 19).

Analysis of variance indicated that the potassium level and light intensity both had a highly significant ( $p = 0.01$ ) influence on the ratio of potassium to dry weight of the leaves. Substrate potassium level and its interaction with light intensity, as well as substrate potassium level and its interaction with substrate temperature also appeared to affect this relationship ( $p = 0.05$ ). All three factors, substrate potassium, light intensity, and substrate temperature had a highly significant influence on this potassium-dry weight relationship with respect to stems but the interaction of these factors was not significant.

### 3. Calcium

Calcium content was tabulated both in terms of the average total





calcium content per plant (Table 20) and as percent of dry weight (Table 21).

Under the low level of potassium, calcium content of the plants tended to increase with increasing substrate temperature under both levels of light intensity (Table 20). Under the high level of substrate potassium, calcium content increased with increasing substrate temperature up to 23.9 C after which it leveled off. The same trend was observed with the leaves and stems taken separately.

The calcium of the plants expressed as percent of dry weight showed a trend of moderately decreasing levels in the plants with increase in substrate temperatures. The maximum calcium content was at a substrate temperature of 29.4 C, low light intensity, and low substrate potassium (Table 20) but on a dry weight basis the maximum calcium content occurred in plants at the 12.8 C substrate temperature (Table 21). The calcium content as percent of dry weight was higher at low light intensity than high light intensity in combination with the low level of substrate potassium (Table 21). However, actual calcium content on a per plant basis was higher under high light intensity (Table 20).

Under the high substrate potassium level there were no significant differences between high and low light intensity treatment with regard to effect on calcium content as percent of dry weight.

#### 4. The pH of nutrient solutions

The pH of nutrient solutions used to feed the tomato plants under the 3 temperature, 2 light intensity and 2 substrate potassium treat-



Table 20. Total calcium of tomato plant tops grown under 2 potassium and 3 temperature substrate levels and 2 levels of light intensity

Treatment			Average total $\text{Ca}^{++}$ content per plant (g)	
Substrate temperature (C)	Light intensity (f.c.)		4 meq $\text{K}^+$ /liter	12 meq $\text{K}^+$ /liter
Leaves	12.8	750	*0.190 a	0.191 a
		1500	0.212 ab	0.177 a
	23.9	750	0.315 ef	0.265 cd
		1500	0.309 def	0.302 def
	29.4	750	0.323 f	0.250 bc
		1500	0.328 f	0.277 cde
Stems	12.8	750	0.045 a	0.048 a
		1500	0.065 ab	0.054 ab
	23.9	750	0.077 bc	0.081 bcd
		1500	0.115 e	0.095 cde
	29.4	750	0.100 cde	0.076 bc
		1500	0.113 e	0.106 de
Whole plants (leaves & stems)	12.8	750	0.236 a	0.240 a
		1500	0.277 ab	0.231 a
	23.9	750	0.392 de	0.345 cd
		1500	0.424 e	0.397 de
	29.4	750	0.423 e	0.326 bc
		1500	0.441 e	0.384 de

\*Figures not followed by the same letter, within or between columns within each group (i.e. leaves, stems, whole plants) are significantly different from each other ( $p = 0.05$ ) according to Duncan's multiple-range test.



Table 21. Calcium content as percent of dry weight of tomato plant tops grown under 2 potassium and 3 temperature substrate levels and 2 levels of light intensity

Treatment			Average $\text{Ca}^{++}$ content per plant (Percent of dry weight)	
Substrate temperature (C)	Light intensity (f.c.)		4 meq $\text{K}^+$ /liter	12 meq $\text{K}^+$ /liter
Leaves	12.8	750	* 2.50 e	1.74 abc
		1500	1.83 bc	1.51 ab
	23.9	750	2.28 e	1.70 abc
		1500	1.96 cd	1.53 ab
	29.4	750	2.21 de	1.69 abc
		1500	1.88 c	1.49 a
Stems	12.8	750	1.74 d	1.16 ab
		1500	1.15 ab	0.96 a
	23.9	750	1.31 abcd	0.98 a
		1500	1.65 cd	0.89 a
	29.4	750	1.62 bcd	1.02 a
		1500	1.29 abc	0.89 a
Whole plants (leaves & stems)	12.8	750	2.31 f	1.58 bcd
		1500	1.61 bcd	1.32 ab
	23.9	750	1.99 e	1.46 abc
		1500	1.87 de	1.30 a
	29.4	750	2.04 ef	1.46 abc
		1500	1.68 cd	1.26 a

\*Figures not followed by the same letter, within or between columns within each group (i.e. leaves, stems, whole plants) are significantly different from each other ( $p = 0.05$ ) according to Duncan's multiple-range test.



ments were monitored during the growing period to determine if the various treatments had a significant effect on altering the pH (Table 22). pH increased with increasing substrate temperature from 12.8 C to 23.9 C but no further significant increase occurred from 23.9 C to 29.4 C.

Analysis of variance indicated that only substrate temperatures had a highly significant affect on altering pH.





Table 22. Changes in the pH of nutrient solutions 7 days after being applied to plants growing under 2 potassium and 3 temperature substrate levels and 2 levels of light intensity

Treatment		Change in pH of nutrient solutions 7 days after application (Initial pH = 5.6)	
Substrate temperature (C)	Light intensity (f.c.)	4 meq K <sup>+</sup> /liter	12 meq K <sup>+</sup> /liter
12.8	750	* + .83 a	+ .80 a
	1500	+ .87 a	+ .88 a
23.9	750	+ 1.80 b	+ 1.70 b
	1500	+ 1.85 b	+ 1.53 b
29.4	750	+ 1.75 b	+ 1.73 b
	1500	+ 1.90 b	+ 1.77 b

\*Within or between columns figures not followed by the same letter are significantly different from each other ( $p = 0.05$ ) according to Duncan's multiple-range test.



## Discussion

Magnesium is particularly subject to a number of interactions with other nutrient elements. From the results of these studies it is evident that the substrate temperature and light intensity has an influence on these interactions and the subsequent uptake of major cations.

It is clear that soil temperature has an important part to play in the growth of tomato plants in the greenhouse. Results of this study confirm that substrate temperature does influence the growth of tomatoes in the greenhouse. The plant height increased with an increase in substrate temperature from 12.8 C to 23.9 C and then decreased at 29.4 C (Table 1). This is in agreement with an observation of Canham (1964). He indicated that soil temperatures higher than 57 F (17 C) - up to 77 F (25 C) in fact - have a beneficial effect on the rate of vegetative growth which should be reflected in subsequent crop yield. Tomato plants will grow faster at soil temperatures up to 77 F and this is a factor which should be under the complete control of the grower.

The higher substrate temperature and substrate potassium appeared to hasten maturity of the first flower buds. However, the height of the first flower cluster of tomato plants was not influenced by the substrate temperature and potassium nutrition (Table 2). The maximum dry weight was obtained when the substrate temperature was at 23.9 C for both levels of substrate potassium (Table 3). The growth (height and dry weight) was optimal at substrate temperature of 23.9 C



and was reduced at the temperature treatment above this. The substrate temperature and the potassium level each influenced the plant growth independently but no interaction of the two factors was evident. These effects of substrate temperature support Canham's findings (1964). Similar experiments by Kabu also indicated an increase in growth (dry weight) with the higher level of substrate potassium (Kabu and Toop 1970b).

It has been shown by many workers that the rate of uptake of various soil nutrients is dependent on soil temperature. The total magnesium content in the plant as well as the content expressed as percent of dry weight was greatest at 29.4 C under the low level of substrate potassium (Table 4 and 5). When the potassium supply was low, the magnesium content of the plants increased with increase in substrate temperature throughout the range of treatment temperatures, whereas at the high level of potassium the magnesium content increased up to the treatment temperature of 23.9 C above which it decreased. This is in agreement with an observation of Kabu and Toop (1970b) that high root-medium temperature hinders magnesium uptake under conditions of high substrate potassium. The interaction between substrate potassium and the substrate temperature was highly significant. This indicates that high substrate temperature and high substrate potassium level could contribute to the problem of potassium-induced magnesium deficiency. The magnesium deficiency in greenhouses, in spite of normal substrate magnesium levels, are frequent on crops such as tomatoes, cucumbers and chrysanthemums. This phenomenon might be explained as a potassium-magnesium antagonism favored by warm tempera-





ture. The superior growth response of tomatoes in ground beds as compared with those grown in raised benches could be interpreted as a consequence of the better buffering capacity of the ground benches against high day temperatures.

The magnesium tended to accumulate in the leaves rather than the stems or roots (Table 5). This agrees with the results of previous workers including Kabu and Toop (1970a).

Substrate temperature also affected the potassium uptake of tomato plants. The total uptake of potassium was affected by substrate temperature and potassium nutrition (Table 6). As might be expected the plant potassium increased when substrate potassium was raised regardless of substrate temperature. With regard to temperature effects, the plant potassium content tended to increase with increase in temperature only up to 23.9 C after which it dropped. However, on a percent dry weight basis it appeared to increase with increase in temperature throughout the range of temperature treatments but this trend was consistent only at the lower level of substrate potassium. However, this is explained by the fact that dry weight was substantially reduced at the highest substrate temperature thus increasing the ratio of potassium to dry weight. Kabu and Toop (1970c) observed slightly different results. They found that the potassium content as percent of dry weight under the low level of substrate potassium showed an increasing trend up to the substrate temperature of 23.9 C. Further increase in temperature to 29.4 C resulted in a depression in potassium content as percent of dry weight. They found that under the high substrate level of potassium highest content of the plants





was at 12.8 and 29.4 C and did not show any consistent trends. Results of this study confirm their findings with regard to this temperature effect at the high substrate potassium level.

With regard to the uptake of calcium there is a trend toward decreased calcium uptake under high substrate potassium and higher temperatures (Table 8). This is in agreement with observations of Mulder (1956) and Kabu and Toop (1970a). Mulder reported that the absorption of calcium may be depressed by excessive amounts of potassium or magnesium. Results of this study confirm that substrate potassium affects the absorption of calcium by tomato plants. The calcium as percent of dry weight was found to be higher under low potassium compared with high potassium levels at all levels of substrate temperature (Table 9). The substrate temperature did not appear to affect the absorption of calcium to any extent.

Under the higher substrate potassium level there were no significant differences between temperature treatments; under the lower potassium substrate level differences were significant only between the lowest and highest substrate temperatures. Arye and Shulman (1971) reported a marked increase in calcium content of apple tree leaves at a root temperature of 25 C with increases in the potassium level of the nutrient solution. At the root medium temperature of 25 C, however, leaf calcium decreased with increases in potassium levels. These results appear to contradict those reported here or by other workers such as Mulder (1956) but the differences in kind of plant material used and experimental procedures could account for this difference in results.



Plants such as tomatoes, beans, cereals and many ornamentals that grow best in unshaded conditions make very satisfactory growth under quite a range of light intensities. In these studies tomatoes were grown under two light levels both of which were relatively low in comparison to full sunlight. However, these experiments showed that difference in light intensity even at this relatively low level can cause differences in plant growth and ability to absorb mineral nutrients.

At the lowest substrate temperature (12.8 C) and the higher light intensity the plants were taller and potassium substrate level appeared to have little influence as compared with the low temperature plants growing under the low light intensity where high substrate potassium appeared to compensate for reduced light to some extent (Fig. 1). Farmer (1970) found that Aspen height diminished when light intensity was reduced from 1700 to 500 foot candles. This is in agreement with the results reported here but only for a substrate temperature of 12.8 C. The substrate temperature in Farmer's experiment was 25 C. At the higher substrate temperatures (23.9 and 29.4 C) the light intensity appeared to be a major factor for plant growth. The plants receiving higher light intensity tended to be shorter than those receiving the lower light intensity under both levels of substrate potassium (Fig. 2 and 3). As substrate temperature was increased the effect of potassium on plant height decreased and the effect of light intensity increased.

A reduction of light intensity from 1500 foot candles to 750 foot candles caused a marked change in plant internode length



(Table 11). Differences in plant height were due to differences in internode elongation rather than differences in numbers of internodes produced. This is in agreement with observations of Kedar and Retig (1968).

Under different light intensities there were significant differences in the height of the first flower cluster mainly between light treatments but also between some substrate potassium and substrate temperature treatments as well (Table 12). In the greenhouse studies (Experiment I) where light intensity was not controlled substrate potassium and substrate temperature treatment had no significant effect on the height of the first flower cluster (Table 2).

High potassium levels coupled with higher light intensity and higher substrate temperatures appeared to hasten maturity of the first flower buds (Table 13). This agrees with the pattern of results in Experiment I where high potassium and high substrate temperature favored early flowering as well. These results could be of practical significance to the commercial grower.

The thickness of tomato plant stems apparently is affected by potassium levels, light intensity and substrate temperature (Table 14). It is standard practice in greenhouse production, particularly of chrysanthemums, to increase potassium fertilization as the crop matures in order to improve stem strength. This toning of stems with potassium is particularly effective when light conditions are poor (winter months). The results of these experiments indicate that both light and potassium fertilization do indeed have a very significant effect on stem diameter and this in turn would undoubtedly





improve stem strength as well. On the basis of these results it would appear that in commercial greenhouse production if soil temperatures could be raised when light conditions are poor it should help to improve the stem quality of the crop. It further emphasizes the importance of the standard recommendation that greenhouse crops be watered with warm water rather than cold water. As indicated earlier these conditions of warm substrate temperatures and high substrate potassium also favor earlier maturity of the first flower cluster of tomatoes.

With regard to the effect of light intensity on the mineral content of the plant tissue, results of this study confirm previous results (Kabu and Toop 1970c) that significantly more magnesium as percent of dry weight is found in plants under low light intensity than under higher light intensity regardless of levels of substrate potassium or substrate temperatures. From the data (Table 17) it would appear that high light intensity and high potassium substrate levels would tend to aggravate the problem of potassium-induced magnesium deficiency. The interaction between the potassium and light intensity factors should contribute more to the problem of potassium-induced magnesium deficiency than would the interaction between substrate temperature and substrate potassium. A comparison of the results of Experiment I and Experiment II support this statement. Statistical analysis did not support the possibility that substrate temperature alone has a direct effect on potassium-induced magnesium deficiency.





The total uptake of potassium was affected by substrate temperature, light intensity and potassium nutrition (Table 18). The leaf potassium and stem potassium increased when potassium level was raised in the nutrient solution. This is in agreement with the findings of Kabu (1970c). He indicated a trend toward higher potassium content under reduced light when analyzing indicator leaves for potassium content. These results (Table 18) also show a trend toward higher amounts of potassium in the entire plant tops with a reduction in the level of light intensity. Total uptake of potassium appears basically to be a function of plant growth and the level of fertilization of potassium. The potassium content as percent of dry weight was remarkably different under the two light intensities (Table 19) regardless of substrate temperature. The maximum potassium uptake occurred at low light intensity in combination with high substrate temperature under high level of substrate potassium (Table 18 and 19). Potassium level and light intensity appear to be the main factors influencing the ratio of potassium to dry weight in the leaves. Substrate potassium level and its interaction with light intensity, as well as substrate potassium and its interaction with substrate temperature are all affecting this relationship.

The calcium content as percent of dry weight tended to be higher at low light intensity than high light intensity particularly at the low level of substrate potassium (Table 21). This is not in agreement with the results of Kabu (1970c). He indicated that the tissue samples taken fourteen weeks after transplanting from plants



under reduced light intensity had relatively less calcium content in them than did those from the plants grown under full light. However, it must be pointed out that in Kabu's experiments only indicator leaves were analyzed not the entire leaves or tops, the plants were more mature (14 weeks old) and the levels of light were at a higher range than used in these experiments.

With regard to changes in pH of the nutrient solutions under various treatment regimes results of this study indicate that only substrate temperature treatments had any effect and this effect was significant only between the 12.8 C and 23.9 C treatments. Since substrate temperature did not significantly affect uptake of any of the cations involved in these studies it can be assumed that the changes in pH were not significant in affecting the results. Furthermore, other workers have found little effect of nutrient media pH over the wide range of 4.0 to 9.0 on the uptake of inorganic nutrients from culture solution (Shine 1939 and Olsen 1953).

In conclusion it might be stated that the results of these studies have some practical application to the commercial production of tomatoes and perhaps other crops under glass as well. First of all these studies give further support to the premise that high levels of substrate potassium do suppress the uptake of magnesium. However, this potassium-magnesium antagonism appears to be enhanced by high light intensity and particularly high light intensity in combination with low substrate temperature. This combination of factors could occur in greenhouses in late spring. Reference to the practical



importance of potassium nutrition in greenhouse crops has already been made. The fact that high substrate potassium under low light conditions improves stem growth emphasizes the importance of having adequate potassium available to greenhouse tomatoes and other crops during the winter season. Furthermore, the fact that low light enhances magnesium uptake helps to offset the effect of high potassium on reducing magnesium uptake at this season of the year. During the spring, summer and early fall when light conditions are good high potassium is less important for stem growth and should be reduced in greenhouse soils in order to help compensate for the effect of high light on restricting magnesium uptake.





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